

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
14 June 2001 (14.06.2001)

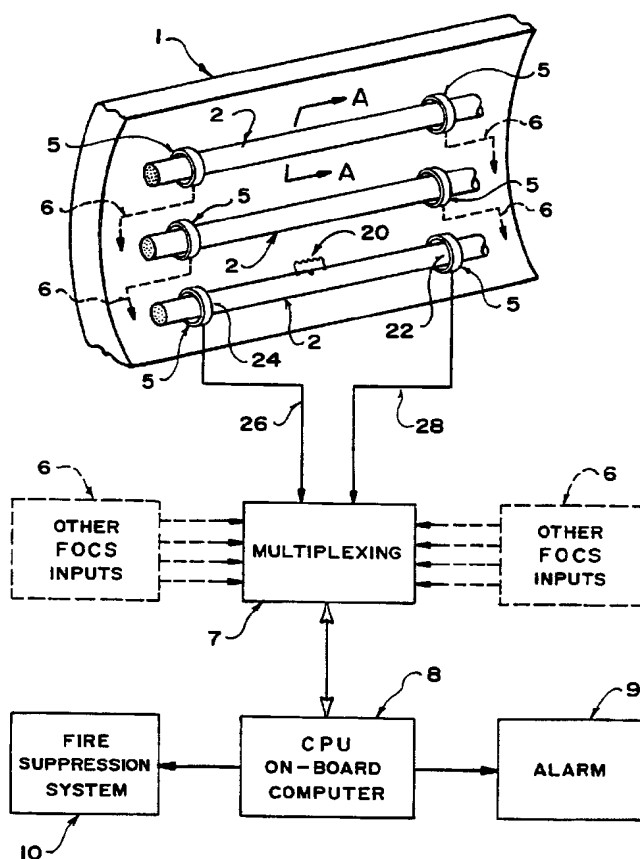
PCT

(10) International Publication Number
WO 01/42802 A1

- (51) International Patent Classification⁷: G01R 31/12, H02H 1/00, G01R 31/08
- (21) International Application Number: PCT/CA00/01452
- (22) International Filing Date: 8 December 2000 (08.12.2000)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
2,291,939 8 December 1999 (08.12.1999) CA
- (71) Applicant and
(72) Inventor: ORTON, Harry, E. [CA/CA]; 1894 Layton Drive, North Vancouver, British Columbia V7H 1X9 (CA).
- (74) Agent: GREEN, Bruce, M.; Oyen Wiggs Green & Muttala, 480-601 West Cordova Street, Vancouver, British Columbia V6B 1G1 (CA).
- (81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, CZ (utility model), DE, DE (utility model), DK, DK (utility model), DM, DZ, EE, EE (utility model), ES, FI, FI (utility model), GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (utility model), SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.
- (84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE,

[Continued on next page]

(54) Title: METHOD FOR DIAGNOSING DEGRADATION IN AIRCRAFT WIRING



(57) Abstract: Wiring in new and older aircraft use bundled insulated conductors that are subject to deterioration over time that can result in on-board fires, loss of in-flight control and eventual crashes of the aircraft. The present invention provides a diagnostic method which permits the on-line and non-destructive diagnosis of the insulation degradation in a portion of the wiring comprising: a) measuring the current flow at locations of the aircraft wiring utilizing an optical current sensor with a bandwidth of dc to 50 kHz; b) determining the current flow within a high frequency bandwidth; and c) analysing the results of the current flow differential determination and initiate the following: i) detect and locate the point of cable failure; ii) initiate an alarm annunciation; and iii) initiate an on-board sectionalized fire suppression system.



IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Published:

- *With international search report.*
- *Before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments.*

METHOD FOR DIAGNOSING DEGRADATION IN AIRCRAFT WIRING

Technical Field

5

The invention relates to a method for diagnosing degradation in electrical wiring, and more particularly to a method for diagnosing degradation in aircraft wiring insulation that can be incorporated into the on-board computer of an aircraft for fault location, early warning and initiation of the fire suppression system to prevent disastrous aircraft crashes.

10

Background Art

Control and power supply wiring on commercial and military aircraft and vehicles is provided by low voltage cables that are typically insulated with PTFE (polytetrafluoroethylene) or polyimide, sometimes referred to by the trade names Hypolon™ or Mylar™ insulation. PTFE offers high temperature resistance, high dielectric strength, fluid resistance and low smoke generation. Its weaknesses include susceptibility to cold flow and low dynamic cut-through resistance. Polyimide has all of the properties of PTFE but has improved resistance to dynamic cut-through. Unfortunately polyimide has been found to be susceptible to arc propagation and degradation due to hydrolysis.

15

20

Such control cables typically consist of central solid or stranded conductors of copper or aluminum with an insulating layer, twisted in pairs, usually in bundles of 36 pairs or more and protected by a jacket of tough polymer material to prevent abrasive or mechanical damage during installation, maintenance and operation of the aircraft. The insulation of such control cables has a typical life time of about 30 to 40 years. However, various factors can lead to premature degradation of the insulation resulting in the deterioration of the electrical and physical properties of the insulating material and to eventual failure of the cable. These factors can include loss of plasticizer with time and temperature, hydrolysis, cold flow, filamentary alignment of the insulation fibres making any insulation tapes susceptible to cracking, unravelling of taped insulation with age, and loss of dielectric, chemical and mechanical properties due to temperature cycling and high temperature

25

30

35

- 2 -

operation. Deterioration of the insulation mechanical properties can be so extensive that cracking and opening of the insulation material can occur. Many older commercial and military aircraft are nearing the end of their service lives but are still operating with possible suspect wiring that could lead to major problems without any warning.

At 400 Hz operation, the normal voltage frequency in these vehicles, sparking to the grounded frame or fuselage and between wires can lead to the catastrophic failure of the control wiring and/or the power supply to electrical servo-motors used to control the plane engines and the flight system. Eventually fire can result in the wiring with complete loss of control of the aircraft. Smoke is a by-product of the event placing personnel at risk.

It is important therefore for aircraft operators to be able to test power and control cables for degradation to allow replacement prior to failure and to permit an orderly replacement schedule. Preferably such testing would be done "live", that is without de-energising the cable prior to testing. There is therefore a need for a diagnostic method which permits on-line, non-destructive live diagnostics in aircraft wiring.

20

Disclosure of Invention

The invention provides a method of on-line diagnosis of insulation degradation in a portion of an aircraft wiring cable comprising the steps of:

- i) measuring the current flow at two locations on said cable utilizing an optical current sensor with a bandwidth of dc to 50 kHz;
- ii) determining the current flow difference at one or more frequencies in the range 10 kHz to 50 kHz; and
- iii) analyzing the results of the current flow difference to locate a potential cable wiring fault.

30

Preferably, the current flow measurement is carried out at multiple sectionalized locations in the aircraft.

- 3 -

Brief Description of Drawings

In drawings which illustrate a preferred embodiment of the invention:

- 5 Fig. 1 is a schematic illustration and block diagram of an aircraft wiring system with the proposed diagnostic; and
 Fig. 2 is a cross-section taken along lines A-A of Figure 1 of a typical wiring cable used in an aircraft.

10 Best Modes for Carrying Out the Invention

- With reference to Figures 1 and 2, a standard aircraft wiring cable (not to scale), designated as 2, carries an electrical current, typically from a few milliamperes to 10's of amperes at 400 Hz. The cable consists of solid or
15 stranded conductors of copper or aluminum, insulated with PTFE or Polyimide and twisted in pairs 3 and bundled into a large cable with an overall jacket 4. Power conductors are typically single core, whereas the control cables are twisted pairs. Some of these cables also carry direct current, although most carry the 400 Hz ac current generated by the airplane's generator. These cable
20 bundles are mounted on the aircraft fuselage 1 or in cable trays and electronics bays inside the aircraft.

- Extremely accurate optical current sensors 5, which may be fibre, slab or crystal are now available to measure the flow of current in the aircraft
25 wiring. Such sensors have a resolution of 5×10^{-6} amperes and a bandwidth of dc to 50 kHz. Optical sensors of this general type are typically manufactured by Sumitomo in Japan and others. A suitable optical current sensor is wrapped around or clipped over the cables 2 at two spaced locations 22, 24. The light within the fibre, slab or crystal is perturbed by the electromagnetic field
30 produced by the current in the conductor and the sensor can be calibrated to measure the current in the conductor with sufficient accuracy and linearity. The output from each optical sensor is communicated to the central processing unit or CPU 8 via conductors 26, 28 and a multiplexer 7 that allows

- 4 -

simultaneous processing of multiple signals 6 from multiple fibre optic current sensors. The CPU 8 calculates the difference between the cable conductor current flows at 22 and 24 at different frequencies, within a bandwidth excluding 400 Hz. To reduce the effects of background noise, time averaging
5 of the data may be carried out over an extended period. Since sparking or an arc discharge 20 generates a high frequency component in the range of 10 kHz to 50 kHz, readings are taken at frequencies in the 10 kHz to 50 kHz range. The differential is then processed by the CPU 8 at those frequencies, the data is analyzed by the CPU and the presence and location of a potential cable wiring
10 fault may be indicated based on that analysis. The CPU will generate an alarm 9 and depending upon the received signal level from the sensor will initiate a sectionalized fire suppression system 10.

The location of the cable wiring fault or sparking may be calculated by
15 the CPU 8 using a technique called time domain reflectometry or TDR. This method is disclosed in the following publication: Matthew S. Mashikian, "Partial Discharge Location as a Diagnostic Tool for Power Tools" 1999 *IEEE/PES Transmission and Distribution Conference*, New Orleans La., April 11-16, 1999, Panel on Diagnostic Measurement Techniques for Power Cables.
20 See in particular Figure 3.

Single, open-ended current sensors 5 can also be positioned at single locations on cables which are connected to the aircraft chassis or ground in order to detect sparking or different harmonics. A second diagnostic may also
25 be performed, namely determining the harmonic component of the 400 Hz insulation leakage current to establish the degree of insulation deterioration that has occurred. A badly deteriorated cable will show a leakage current (differential) in a given range at a particular frequency. The method of carrying out the harmonic current analysis is described in the following publications: K.
30 Hirotsu, K. Hosoe et al., "Development of Hot-line Diagnosis Method for XLPE Cables by Measurement of Harmonic Current" in *Proceedings of the Symposium on Electrical Insulation Materials*, Osaka Japan, september 1994, Vol. 26, pp. 455-458; J. Densley, "Aging and Diagnostics in Extruded Insulation for Power Cables" in *Proceedings of the 6th International*

- 5 -

Conference on Conduction and Breakdown in Solid Dielectrics, June 22-25, 1998, Vasteras, Sweden; J. Densley, "Didactic", *IEEE ICC Minutes*, November 1997, St. Petersburg, Florida.

5 This diagnostic thus can provide an early detection of impending problems and allow for corrective measures to be taken and so avert any chance of a major disaster. By incorporating an electrical diagnostic on the aircraft wiring as an early detection system and interfacing this diagnostic with the on-board computer or CPU of the aircraft, it is possible to provide an early
10 warning alarm and to initiate the fire suppression system while any fire situation is relatively small. Early detection will allow prompt extinction of any fire and minimize the effort needed to extinguish that fire. For example, a sectionalized water mist or nitrogen gas fire suppression would be capable of extinguishing most small fires if initiated while the fire is still small, thus
15 limiting further fire damage and minimizing the risk to personnel. By sectionalizing the aircraft it is possible to contain any fire to that section without jeopardizing other areas of the aircraft. Possible sections on the aircraft would include the power supply generators, the engines, the fuel tanks, the cockpit, the cargo bays, the passenger compartments and the electronics
20 bays. The diagnostic can be installed in new aircraft as well as retro-fitted to older aircraft and can become part of the on-board expert monitoring system already used to detect carbon monoxide, carbon dioxide, oxygen and smoke. Continuous monitoring whenever the aircraft is in operation will add to reliability and operation safety.

25
As will be apparent to those skilled in the art in the light of the foregoing disclosure, many alterations and modifications are possible in the practice of this invention without departing from the spirit or scope thereof. Accordingly, the scope of the invention is to be construed in accordance with
30 the substance defined by the following claims.

- 6 -

WHAT IS CLAIMED IS:

1. A method of on-line diagnosis of insulation degradation in a portion of an aircraft wiring cable comprising the steps of:
 - 5 i) measuring the current flow at two locations on said cable utilizing an optical current sensor with a bandwidth of dc to 50 kHz;
 - ii) determining the current flow difference between said two locations at one or more frequencies in the range 10 kHz to 50 kHz;
 - 10 iii) analyzing the results of the current flow difference to locate a potential cable wiring fault.
2. The method of claim 1 wherein said current flow measurement is carried out at multiple sectionalized locations in the aircraft.
- 15 3. The method of claim 1 further comprising the steps of annunciating an alarm in a central processing unit if a potential cable wiring fault is located.
4. The method of claim 1 further comprising the steps of initiating an on-board fire suppression system if a potential cable wiring fault is located.
- 20 5. The method of claim 1 wherein said analysis is carried out by a central processor.
6. The method of claim 5 wherein said potential cable wiring fault is located by said central processor carrying out a time domain reflectometry technique.
- 25 7. The method of claim 1 further comprising the step of determining the harmonic component of the 400 Hz insulation leakage current to establish the degree of insulation deterioration that has occurred.
- 30 8. In an aircraft or other vehicle having an insulated electrical cable, the improvement comprising providing optical current sensors with a bandwidth of dc to 50 kHz mounted at two spaced locations on said cable for measuring the

- 7 -

current flow at said two spaced locations on said cable, and central processing means connected to said optical current sensors for determining the current flow difference at one or more frequencies in the range 10 kHz to 50 kHz and analysing the results of the current flow difference to locate a potential cable
5 wiring fault.

1/2

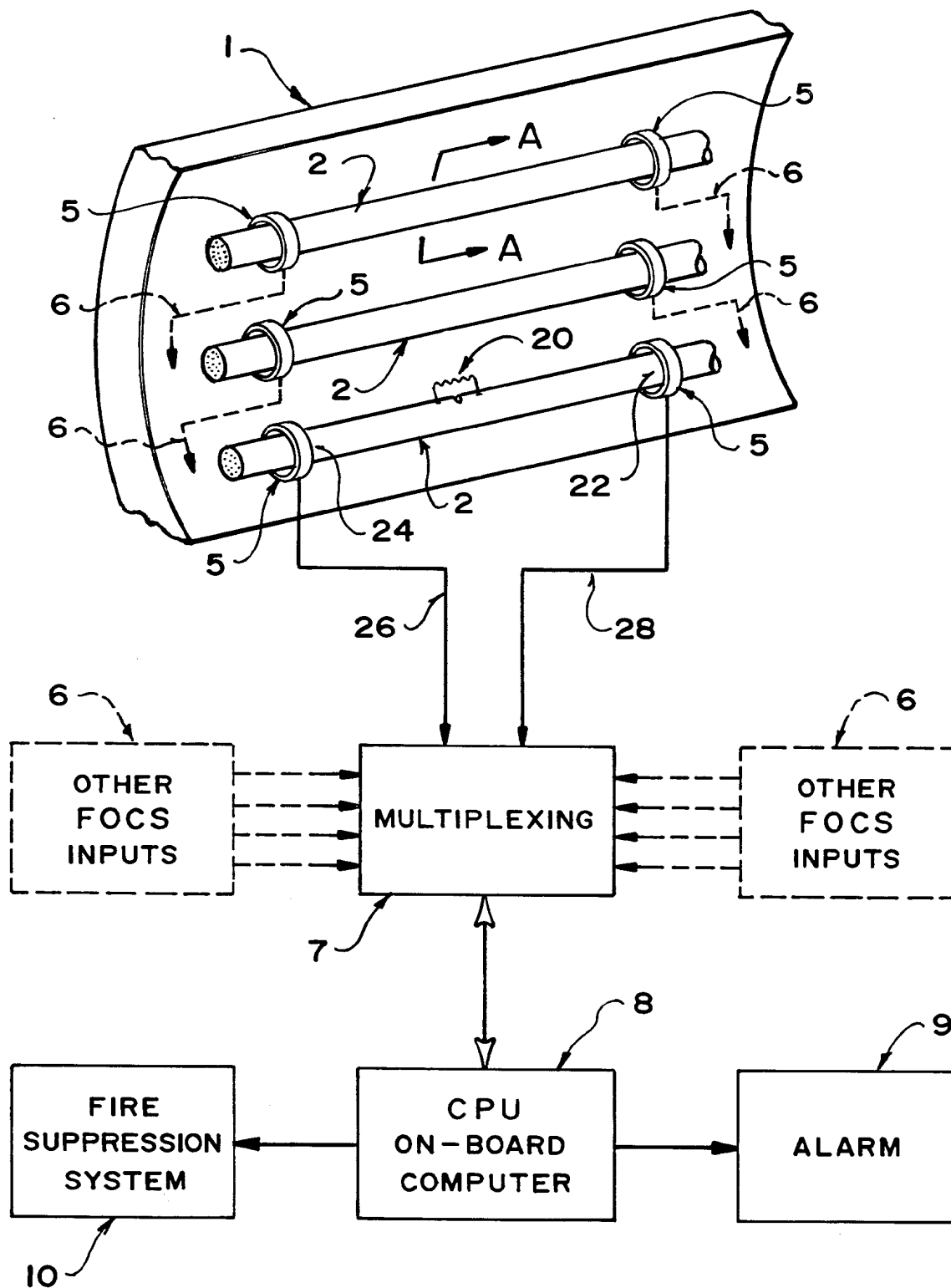


FIG. 1

2/2

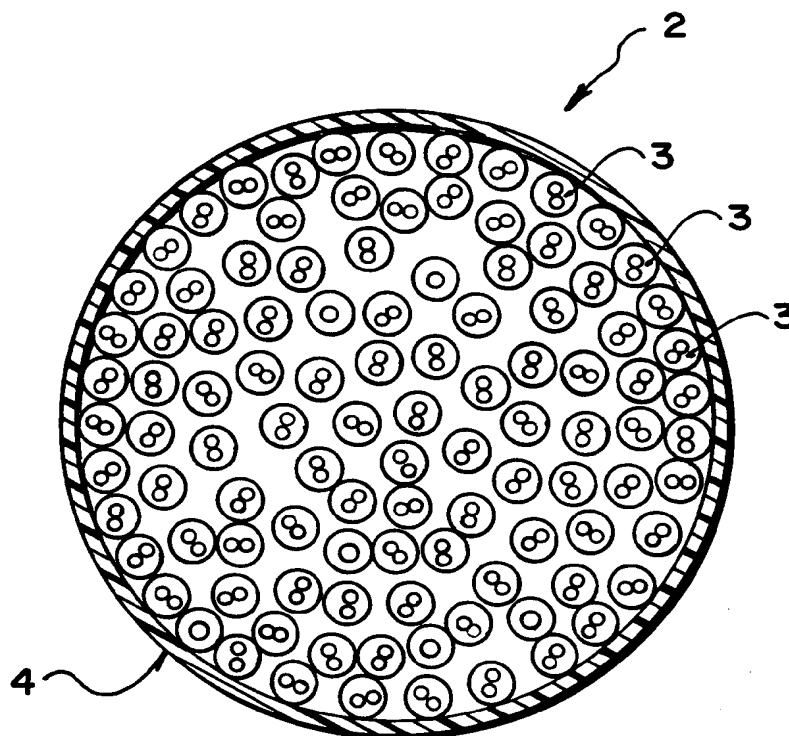


FIG. 2

INTERNATIONAL SEARCH REPORT

International Application No

PCT/CA 00/01452

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G01R31/12 H02H1/00 G01R31/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G01R H02H B64F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 165 803 A (SUMITOMO ELECTRIC INDUSTRIES) 27 December 1985 (1985-12-27) abstract page 7, line 11 -page 8, line 9 figures	1,8
A	US 4 959 792 A (SULLIVAN THOMAS P) 25 September 1990 (1990-09-25) abstract column 1, line 20 - line 24 column 3, line 66 -column 4, line 52 figures	1,8
A	US 4 808 814 A (HOFER BERND ET AL) 28 February 1989 (1989-02-28) column 2, line 19 - line 55 column 5, line 14 - line 58 figure 4	1,8
	--- -/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *G* document member of the same patent family

Date of the actual completion of the international search

9 April 2001

Date of mailing of the international search report

23/04/2001

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Lopez-Carrasco, A

INTERNATIONAL SEARCH REPORT

International Application No

PCT/CA 00/01452

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 479 610 A (ROLL-MECAK DORU T ET AL) 26 December 1995 (1995-12-26) abstract figures	1,8
A	EP 0 411 863 A (MITSUI PETROCHEMICAL IND) 6 February 1991 (1991-02-06) abstract	1,8

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/CA 00/01452

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0165803 A	27-12-1985	JP 1700405 C	14-10-1992
		JP 3067231 B	22-10-1991
		JP 61003075 A	09-01-1986
		AU 580603 B	19-01-1989
		AU 4363985 A	02-01-1986
		BR 8503012 A	11-03-1986
US 4959792 A	25-09-1990	DE 3785062 A	06-05-1993
		DE 3785062 T	30-09-1993
		EP 0235907 A	09-09-1987
		JP 2619867 B	11-06-1997
		JP 62247274 A	28-10-1987
US 4808814 A	28-02-1989	DE 3629430 A	10-03-1988
US 5479610 A	26-12-1995	CA 2175365 A	11-05-1995
		EP 0727048 A	21-08-1996
		IL 111410 A	04-08-1996
		JP 9506448 T	24-06-1997
		WO 9512820 A	11-05-1995
EP 0411863 A	06-02-1991	AT 131935 T	15-01-1996
		CA 2022413 A	01-02-1991
		CN 1049229 A,B	13-02-1991
		DE 69024278 D	01-02-1996
		DE 69024278 T	27-06-1996
		JP 2091420 C	18-09-1996
		JP 3128471 A	31-05-1991
		JP 8007250 B	29-01-1996
		KR 172603 B	30-03-1999
		US 5117191 A	26-05-1992